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ABSTRACT

To test people's ability to underestimate time requirements during planning, researchers conducted three experiments in which subjects had to estimate the time needed to do hypothetical errands in an imaginary town. The subjects comprised three separate groups of students and citizens. Variables tested included the number of errands, the total available time, time required per errand, and travel time. The first experiment confirmed previous findings that people tend to underestimate time requirements and hence plan to do more than they can achieve. The second and third experiments tested two factors influencing time estimation: people's cognitive tendency to plan at high levels of abstraction and the motivational tendency to wish to do all the tasks considered. The cognitive tendency was examined by giving the subjects detailed breakdowns of required actions. The resulting time estimates were higher and more realistic. In the third experiment the errands were assigned levels of importance. Subjects with more important errands had larger underestimates of time requirements. These results lead the authors to suggest that planners should operate at optimal levels of abstraction and should be prevented from incorporating too many tasks in their plans. (RW)

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A RAND NOTE

ESTIMATION OF TIME REQUIREMENTS DURING PLANNING: INTERACTIONS BETWEEN MOTIVATION AND COGNITION

Barbara Hayes-Roth

November 1980

N-1581-ONR

Prepared For

The Office of Naval Research

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PREFACE

This Note documents a series of experiments investigating time estimation during planning. It focuses on people's tendency to underestimate time requirements and, as a consequence, to plan more actions than they can accomplish in the time available for plan execution. The research was supported by the Office of Naval Research, under Contract N00014-78-C-0039. It should be of interest to persons concerned with human planning behavior and with the design of planning aids.

SUMMARY

Effective planning depends, in part, on the estimation of required times for planned actions. If a planner underestimates time requirements, he or she will plan too many actions, and plan execution will overrun the available time. If the planner overestimates time requirements, he or she will plan too few actions, and plan execution will fail to exploit all of the available time. The present research suggests that the former problem, underestimation of time requirements, predominates in human planning behavior. In addition, time stress increases the tendency to underestimate required time. The more difficult it is to fit all actions under consideration into the available time, the stronger the tendency to underestimate time requirements.

In addition to documenting the phenomena described above, this Note suggests two underlying factors which influence planning behavior, a cognitive factor and a motivational factor. The cognitive factor refers to people's tendency to plan at high levels of abstraction. In so doing, they fail to enumerate all of the time-consuming components of planned actions and, as a consequence, systematically underestimate the time required to perform the action as a whole. The motivational factor refers to people's desire to accomplish all of the tasks under consideration. This creates an underestimation bias for time estimates.

The Note concludes with a discussion of two methods for correcting underestimation of time requirements during planning. The first method entails identifying an optimal level of abstraction for planning and inducing planners to operate at that level. The second method entails

regimenting planners' time-estimation behavior to protect it from motivational factors inherent in particular planning contexts.

ACKNOWLEDGMENTS

Doris McClure and Kay McKenzie conducted the experiments and data analyses reported in this Note. Kay McKenzie also prepared the document. David Kanouse consulted on the attribution problem in learning from experience. Cathleen Stasz provided helpful comments on an earlier draft of the Note.

CONTENTS

PREFACE iii

SUMMARY v

ACKNOWLEDGMENTS vii

Section
I. INTRODUCTION 1

II. EXPERIMENT 1 7
Method 7
Results 9
Discussion 11

III. EXPERIMENT 2 14
Method 15
Results and Discussion 17

IV. EXPERIMENT 3 19
Method 19
Results and Discussion 20

V. CONCLUSIONS 23
The Attribution Problem 25
Correction of Biases in Resource Estimation 26

REFERENCES 29

I. INTRODUCTION

Planning is a familiar cognitive process. It figures in a variety of common activities, such as managing a household or driving to a friend's house. Planning also plays an important role in many specialized tasks such as building construction or air traffic control.

Effective planning requires several component skills, including situation assessment, generation of alternative actions, estimation of resources required to perform alternative actions, cost-benefit analysis of alternative actions, constraint satisfaction, anticipation of important contingencies, and mental simulation of planned actions. In this Note, we focus on the estimation of time requirements for planned actions.

Time requirements are a major consideration in all planning requiring the selection and sequencing of actions under time constraints. A planner must consider time requirements when selecting actions for inclusion in a plan, weighing the "benefit" of performing each action against its "cost" in time (and perhaps other resources). The planner must also consider time requirements when sequencing actions because different sequences may entail different transition times.

Frequently, the planner has limited prior knowledge of time requirements. In such cases, the planner must estimate time requirements, and the accuracy of these estimates is a limiting factor on the quality of the plan. If the planner underestimates time requirements, the plan will overrun the available time during execution and some planned actions will be foregone. If the planner overestimates time

requirements, plan execution will fall short of the available time and the plan will not accomplish as many actions as it might have.

We have been studying the role of time estimation in people's performance of an errand-planning task (see Hayes-Roth, 1980; Hayes-Roth & Hayes-Roth, 1978, 1979; Hayes-Roth & Thorndyke, 1980). In this task, subjects work with a list of desired errands, prescribed starting and ending times and locations, and a map of the town in which they would "perform" planned errands (see Figure 1). (Subjects do not actually perform errands; they simply generate a plan for performing them.) Ordinarily, there is not enough time to perform all of the desired errands. Therefore, the subject must plan which errands to perform, how much time to allocate for individual errands, the order in which to perform the errands, and the routes to take between successive errands. A sample problem follows:*

> You've just arrived in town by subway (42). You have several errands you would like to get done this morning while you're in town. It's 9:00 a.m. now and you would like to get back to the subway by 11:00 a.m. so that you'll be home by Noon. Here are the errands you want to do:
>
> Deposit your refund at the Oak Street Bank (35)
> Look at the wicker chairs at Pier 1 (51)
> Pick up tickets for the special exhibit at the Museum (22)
> Pick up some items you need from the Pine Street Pharmacy (54)
> Pay your bill at McMahon's Furniture Store (12)
> Buy Spanish-English dictionary for your Spanish class at Benton Bookshop (17)
> Drop off your watch to be repaired at the watch repair (80)
> Pay your fine at the Traffic Court (11)
> Buy stamps at the post office (26)
> Buy album you had wanted at Benton's Records (19)
> Buy the blouse/shirt you had picked out at the clothing store (15 or 34)
> Buy screws to mount wall shelves at the hardware store (77)

* Numbers in parentheses refer to locations shown in Figure 1.

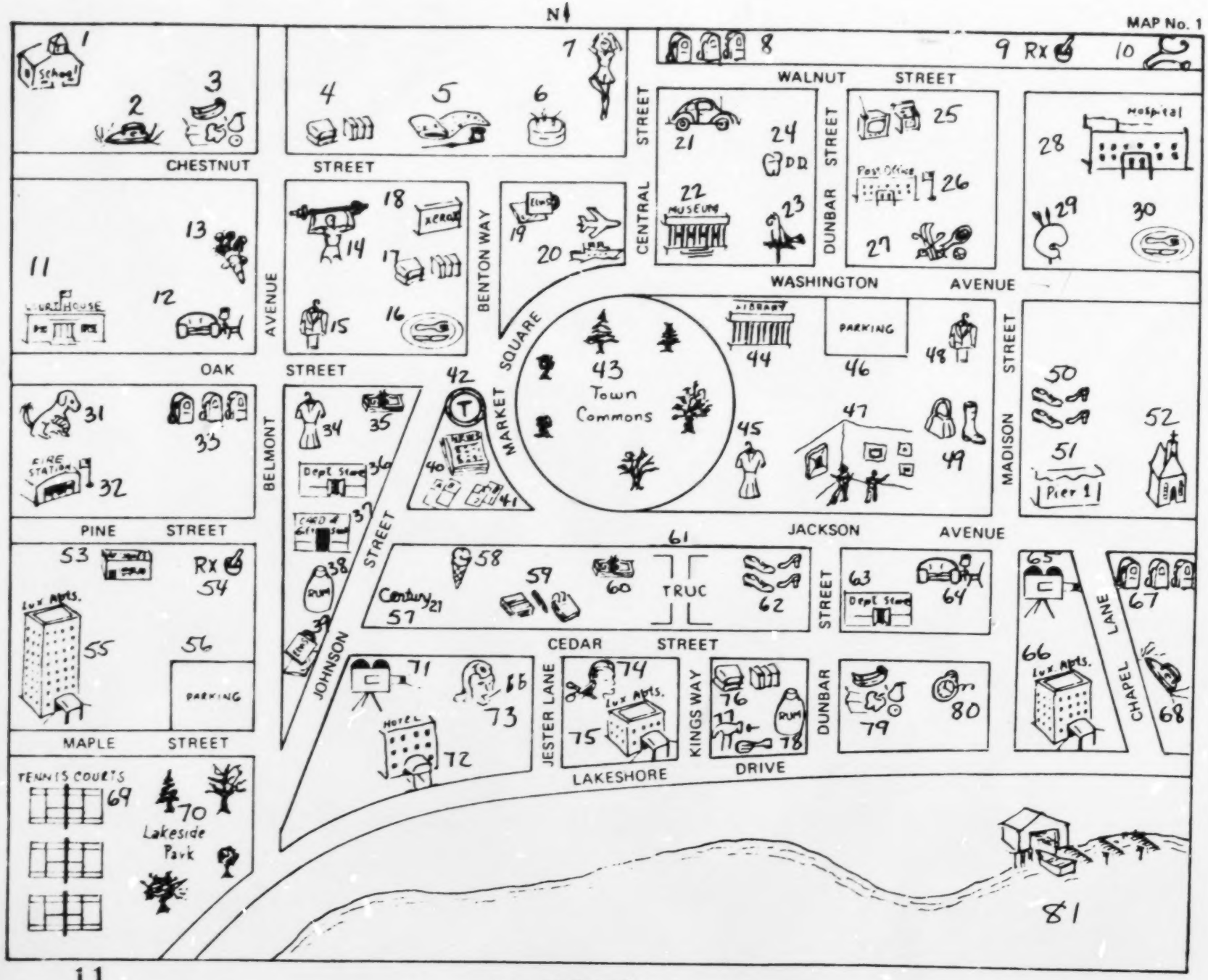

Fig. 1--Town Map

Effective planning requires accurate estimation of individual errand times and travel times for planned routes. By selecting errands with minimal time requirements, the planner can maximize the number of errands accomplished. By sequencing errands to minimize travel time, the planner can maximize the time available for performing errands. Of course, other factors, such as the relative importance of individual errands or constraints on when certain errands can be performed, should also influence the selection and sequencing of errands. Regardless of the selection and sequencing criteria a planner uses, however, he or she must estimate errand and travel times to ensure that the planned activity does not exceed the available time.

We recently conducted a pilot study of time estimation. Five subjects generated plans for six different problems. We then calculated the time required to execute each plan. We based these calculations on objective travel times and normative errand times. We had told subjects in advance how long it would take to "cross town" from north to south and from west to east. Thus, we could simply measure planned routes and compute the corresponding travel times. For errand times, we collected independent time estimates from a separate group of ten judges and used the median time estimate for each errand as its normative time. The sum of the computed travel times and normative errand times for a given plan represents the time required to execute the plan.

The pilot study produced two interesting results. First, subjects produced unrealistic plans. All five subjects systematically overestimated

what they could accomplish in the available time. We computed plan overrun as

$$\frac{\text{(time required to execute a plan - time available for plan execution)}}{\text{time available for plan execution}}$$

Execution times for subjects' plans overran the available time by as much as 90 percent. The average overrun was 36 percent.

The second result was that increased time stress exacerbated subjects' tendency to overestimate what they could accomplish. We evaluated the time stress for a problem as the sum of the normative times required for all errands specified in a problem, divided by the time available for performing planned errands. Thus, it is a measure of the difficulty of performing all of the specified errands in the available time. As time stress increased, subjects' plans overran the available time by increasing proportions, $r = .62$, $p < .001$ (see Figure 2). Although variations in time stress represented different numbers of desired errands and different amounts of available time for executing errands, neither of these variables accounted for the variance in plan overrun.

These results confirm a common informal observation: People habitually overestimate their own productivity. Ordinarily, plan overrun has relatively minor consequences--we inconvenience ourselves and others. However, in many situations, overrunning the time available for plan execution can have more serious consequences. For example, in the construction industry, overrunning planned building time can leave a family temporarily homeless. In business, overrunning planned production time

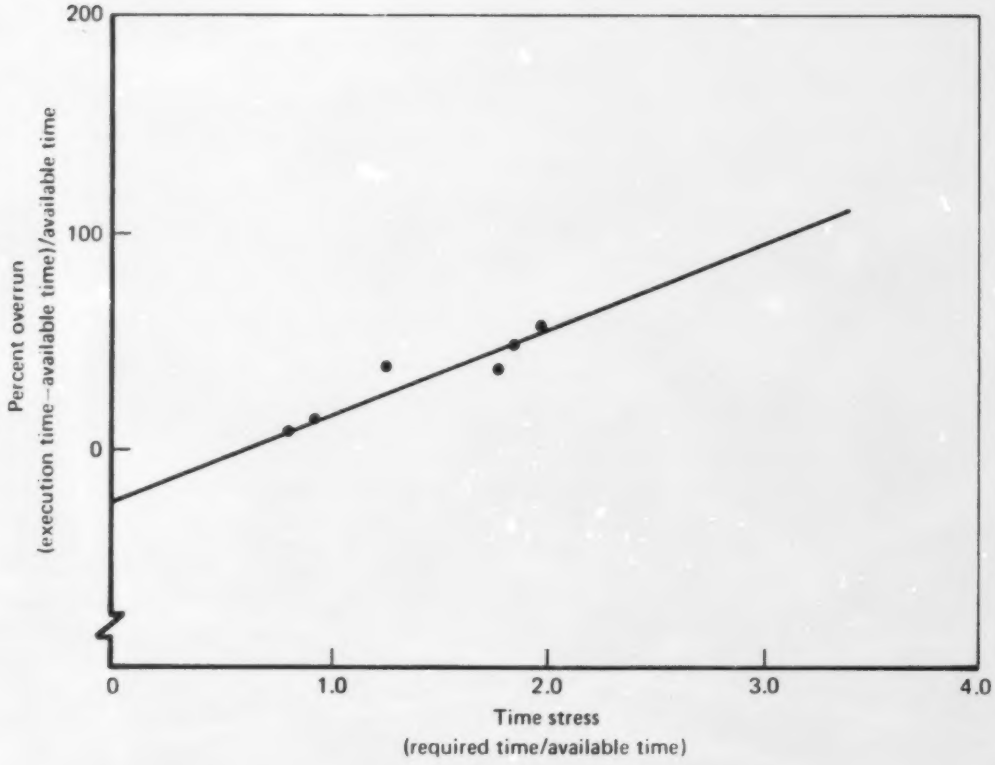

Figure 2

can turn a potential profit into a loss. An understanding of the cognitive bases for plan overrun might enable us to prevent or correct such costly errors. The research reported in this Note represents a first step in that direction.

II. EXPERIMENT 1

In the first experiment, we attempted to replicate the observations discussed above. We manipulated time stress systematically by crossing two variables: number of desired errands (six versus twelve) and available time for performing errands (two hours versus four hours). Averaging across several problems in each condition, these variables produced four levels of time stress: .72 for six errands in four hours; 1.48 for twelve errands in four hours; 1.61 for six errands in two hours; and 3.2 for 12 errands in two hours.

Another innovation in Experiment 1 was the technique used to compute the time required to execute subjects' plans. One limitation of the pilot study was our use of normative errand times. Perhaps subjects seemed to underestimate time requirements simply because they disagreed with the normative judges. Although this would not explain the relationship between time stress and plan overrun, it would inflate subjects' apparent tendency to overestimate what they could accomplish in general. Therefore, instead of using normative errand times to compute plan execution times in this experiment, we used subjects' own independent estimates of individual errand times. These were collected in a separate session, prior to the actual experiment. We used objective travel times for execution time computations, as discussed above.

METHOD

Materials and Procedure. In session 1, subjects made several judgments about each of forty-eight errands, for example, pick up medicine for the dog at the vet, buy a birthday card, discuss vacation plans with

your travel agent. For each errand, subjects indicated (a) whether they performed the errand never, rarely, or frequently; (b) whether the errand was unimportant, important, or very important; and (c) how much time they would require to perform the errand. Subjects were self-paced.

In session 2 (about one week later), subjects formulated plans for each of four problems. All of the errands specified in these problems were drawn from the list of errands subjects had judged in session 1. In addition, each problem specified a starting time and location and an ending time and location. For each problem, subjects indicated (a) which errands they would perform; (b) the order in which they would perform the errands; and (c) the routes they would travel between successive errands. Subjects worked at their own rates.

Design. Each of the four problems a subject solved represented one of four conditions produced by crossing two variables: number of desired errands (six versus twelve) and time available for executing the plan (two hours versus four hours). As discussed above, these four conditions represent different amounts of time stress ranging from .72 to 3.2. We rotated the four conditions across individual problems for different subjects to counterbalance problem effects. Because all subjects saw the four problems in the same order, this rotation also served to counterbalance serial position effects.

Subjects. Twenty UCLA undergraduates participated as subjects.

RESULTS

As discussed above for the pilot study, we computed plan overrun as

$$\frac{\text{(time required to execute a plan - time available for plan execution)}}{\text{time available for plan execution}}$$

We computed execution times as the sum of the computed travel times and the subject's own session 1 errand times for the components of his or her plan.

Figure 3 shows percent overrun as a function of time stress. Each data point represents twenty subjects. In three of the four conditions, subjects' plans overran the available time by over 50 percent. Only for six errands in four hours, where the available time exceeded the time required to perform all the desired errands, did subjects' plans "fit" in the available time. These data confirm our earlier observation that people generally overestimate what they can accomplish in a given period of time.

The results also replicated the relationship between percent overrun and time stress. As time stress increased, subjects' plans overran the available time by increasing percentages of the available time (test for linear trend: $F(1,79) = 46.44$, $p < .001$). Further, both components of time stress influenced plan overrun. Thus, plan overrun increased as the number of desired errands increased ($F(1,76) = 26.66$, $p < .001$) and as the time available for performing errands decreased ($F(1,76) = 25.37$, $p < .001$). The interaction was not significant ($F(1,76) = .03$).

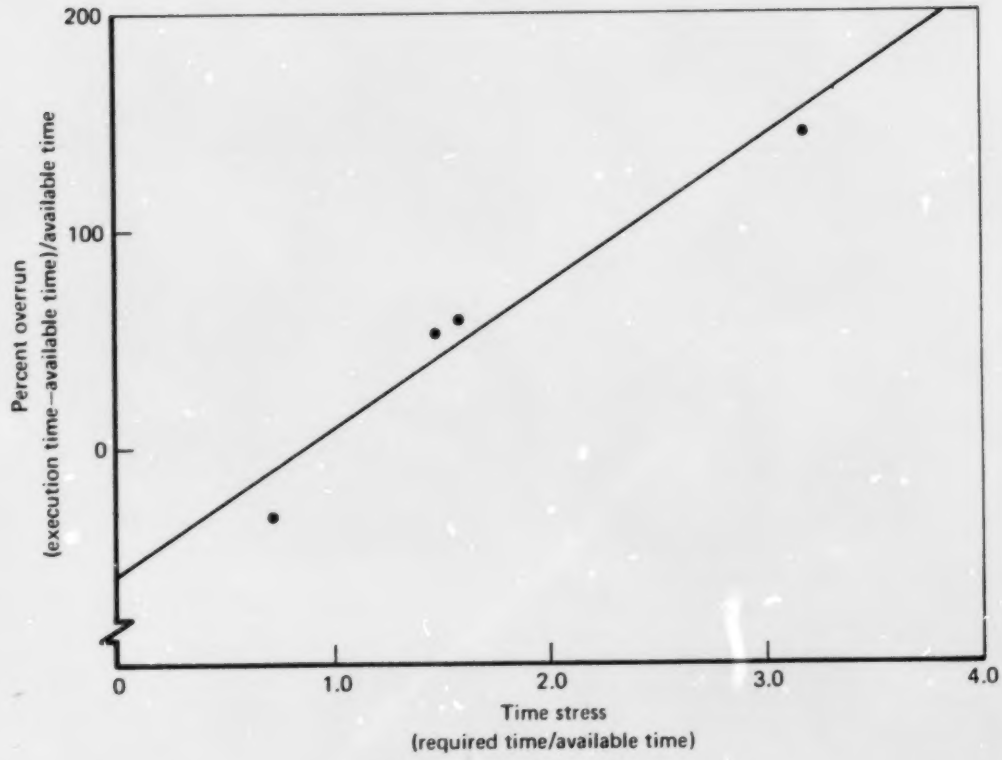

Figure 3

At first glance, these results seem to suggest that subjects completely ignored time constraints while planning. In fact, however, subjects did modify their planning behavior somewhat in response to increases in time stress. As shown in Figure 4, subjects planned smaller percentages of the total number of errands specified in a problem as time stress increased (test for linear trend: $F(1,79) = 14.65$, $p < .001$). Thus, subjects correctly responded to time stress by reducing the quantity of planned activity. However, they failed to reduce it sufficiently to meet actual time constraints.

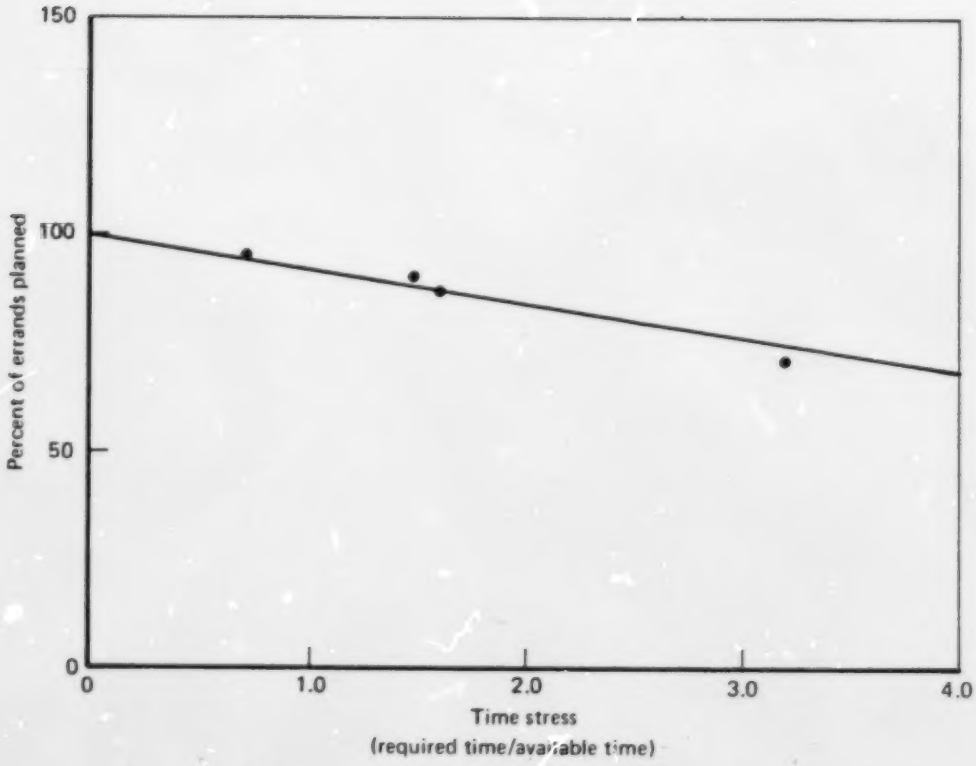

Figure 4

DISCUSSION

Let us consider two explanations for subjects' unrealistic planning behavior, a cognitive hypothesis and a motivational hypothesis.

The cognitive hypothesis has two parts: (a) that people estimate time requirements for plans at relatively high levels of abstraction; and (b) that at higher levels of abstraction, people generate lower time estimates.

Several investigators have suggested that people form plans at different levels of abstraction (Hayes-Roth & Hayes-Roth, 1978, 1979; Sacerdoti, 1974). At one extreme, the planner can form an abstract plan, specifying only the major actions to be taken. At the opposite extreme, the planner can form a very detailed plan, specifying exact sequences of actions and sequences of component operations for performing each action. Presumably, the planner can also estimate the time required to execute a plan at different levels of abstraction. The first part of the cognitive hypothesis simply assumes that planners tend to estimate time requirements for relatively abstract specifications of their plans. Ordinarily, they do not bother to work out time requirements for detailed specifications of their plans.

The second part of the cognitive hypothesis assumes that a planner will generate lower time estimates for an abstract plan than for a more detailed specification of the same plan. Working at the more detailed level would force the planner to enumerate all component actions and to increment the overall time estimate for each one. Working at a more abstract level does not force this systematic attention to component actions. Consequently, the planner's overall time estimate may fail to incorporate component times for all component actions. A plan based on low time estimates would include more errands than the planner could actually accomplish in the available time.

The cognitive hypothesis provides a plausible account of people's general tendency to overestimate what they can accomplish. However, it does not explain why this tendency should increase with time stress. For that, we need the motivational hypothesis.

The motivational hypothesis assumes that people have high aspirations. In the present situation, they wish to accomplish all or most of the errands specified in a problem. People know that there is a certain amount of variability in the time required to perform individual actions. Under time stress, the desire to perform all of the actions biases people's time estimations toward the lower bounds of these distributions. The greater the time stress, the stronger the bias.

The cognitive and motivational hypotheses describe complementary factors that might contribute to people's unrealistic planning behavior. Experiments 2 and 3 test predictions based on each hypothesis.

III. EXPERIMENT 2

As discussed above, the cognitive hypothesis assumes that people's underestimation of required times is partially a function of the level of abstraction at which they generate their time estimates. When people work at a relatively high level of abstraction, they fail to increment their time estimates for all component tasks. When they work at a lower level of abstraction, they reduce this error. If this hypothesis is correct, we should be able to influence the degree of underestimation of required times by influencing the level of abstraction at which subjects work.

Hayes-Roth and Hayes-Roth (1979) postulated four levels of abstraction for the errand-planning task (see also, Hayes-Roth & Thorndyke, 1980). For the present purposes, we need consider only the two lowest levels of abstraction they discussed: procedures and operations. At the procedures level, a subject plans the sequence of individual errands he or she will perform. Time estimates at this level would refer to unitary errands and unitary routes between successive errands. At the operations level, a subject plans the details of individual errands and routes. Time estimates at this level would refer to the subtasks required to accomplish individual errands (e.g., enter the store, find the desired object) and the separate "legs" traversed along a particular route. The cognitive hypothesis predicts that subjects should produce shorter time estimates when they operate at the procedures level than when they operate at the operations level. Experiment 2 tested this prediction.

METHOD

Materials, Design, and Procedure. Three plans were constructed for the experiment. Each plan specified twelve errands requiring the planner to enter a store and purchase some object. Each errand required about fifteen minutes to execute (based on normative data). Plans were accompanied by illustrative maps, as discussed below. Each subject made time estimates for two of the three plans, one in the procedures condition and one in the operations condition. The pairing of individual problems was counterbalanced across subjects.

For the procedures condition, subjects received a plan description and a modified version of the map shown in Figure 1. All street information was removed from the map so that it provided only approximate city-block distance information. It provided no information regarding the constituent legs of routes connecting pairs of errands. However, planned destinations were numbered on the map in accordance with the plan. Based on this information, subjects judged "roughly how long it would take to carry out each errand and roughly how long it would take to travel from one errand to the next." They recorded their estimates on the following kind of form:

Start at the Hospital (28)

ERRAND	ERRAND TIME	ROUTE TIME
Men's Store	_____	_____
Truc	_____	_____

For the operations condition, subjects received a plan description and the map shown in Figure 1 containing all street information. Planned destinations were numbered and routes were marked in accordance with the plan. Based on this information, subjects made "very precise estimates of how long it would take to do each part of each errand and how long it would take to travel each leg of the planned route." In order to facilitate this decomposition process, we provided a more detailed form on which subjects recorded their estimates:

a = enter store
b = find desired object
c = wait in line
d = pay for object
e = leave store

Start at the Hospital (28)

ERRAND	ERRAND TIME a b c d e	ROUTE TIME
Men's Store	___ ___ ___ ___ ___	South on Madison _____ West on Jackson _____
Truc	___ ___ ___ ___ ___	West on Jackson _____ North on Johnson _____ West on Oak _____

For both conditions, subjects recorded the time at which they began reading the problem description and the time at which they finished making time estimates.

Subjects. Eighteen adults between the ages of 18 and 70 responded to a newspaper ad to serve as subjects.

RESULTS AND DISCUSSION

As a check on our manipulation, we compared subjects' task times for the two conditions. As expected, subjects took considerably longer to make detailed time estimates at the operations level than to make rough estimates at the procedures level (16.9 minutes versus 8.1 minutes, $t(17) = 6.32$, $p < .001$).

The results for errand time estimates were straightforward. As predicted, subjects estimated longer times when they worked at a low level of abstraction than when they worked at a high level of abstraction. Their time estimates at the operations level were, on the average, 22 percent higher than those at the procedures level ($t(17) = 1.83$, $p < .05$).

Although we measured travel time estimates independently of errand time estimates, we did not expect that level of abstraction would have a strong effect. For all three plans used in the experiment, most of the thirteen errand-to-errand routes had relatively few legs. Plans 1, 2, and 3 had five, seven, and six one-leg routes, respectively, and for all three plans, five of the remaining routes had only two legs. Routes with only one or two legs do not permit a strong manipulation of level of abstraction for travel time estimates. As a consequence, subjects' travel time estimates did not differ in the two conditions.

These results provide some support for the cognitive hypothesis. When subjects work at a higher level of abstraction, they produce lower time estimates than when they work at a low level of abstraction. If subjects generally work at a high level of abstraction while planning, they will tend to underestimate the time required to accomplish

individual tasks and, as a consequence, overestimate what they can accomplish in the time available for plan execution. Our previous analyses of planning protocols (Goldin & Hayes-Roth, 1980; Hayes-Roth & Hayes-Roth, 1979) suggest that subjects rarely estimate time requirements at a lower level of abstraction than the procedure level during errand planning.

IV. EXPERIMENT 3

As discussed above, the motivational hypothesis assumes that subjects' tendency to plan unrealistically reflects a high aspiration level. Their desire to accomplish all or most of the errands specified in a problem biases them to produce low time estimates and, as a consequence, to plan too many errands. If this hypothesis is correct, we should be able to influence subjects' tendency to overestimate what they can accomplish by influencing their motivation level.

A simple way to influence subjects' motivation level is by manipulating the importance of the errands specified in a problem. The more important the errands are, the more motivated subjects will be to accomplish them, and the more they should overestimate what they can actually accomplish. Experiment 3 tested this prediction.

METHOD

Procedure. Sessions 1 and 2 were similar to those described for Experiment 1. In describing their plans for Experiment 2, subjects also indicated the time at which they would arrive and leave each planned errand.

Materials and Design. Subjects worked with four problems, each specifying twelve errands and providing two hours of execution time. The errands for each problem were chosen on the basis of importance ratings collected from twenty other subjects. The median rating given to each errand was used as its normative importance value. Two problems were then constructed for each of two conditions. High-motivation problems specified twelve very important errands (normative importance

values of at least 4.0 on a 5-point scale). Low-motivation problems specified twelve moderately important errands (normative importance values of 2.5 or less). The problems were identical in other respects. Individual errands required about fifteen minutes. Thus, to accomplish all twelve errands in a problem would require about three hours plus travel time. Subjects worked on the problems in random order.

Subjects. Thirty-one UCLA undergraduates participated as subjects.

RESULTS AND DISCUSSION

As a check on our materials, we assessed subjects' session 1 ratings of the errands specified in the two sets of problems. For high-motivation problems, subjects rated a mean of 9.0 of the twelve errands per problem as very important; for low-motivation problems, they rated a mean of 7.63 errands as only moderately important. Thus, our manipulation appears to be fairly reliable across subjects.

The results were straightforward. Subjects' plans overran the available time by a greater proportion for high-motivation problems (overrun = 39 percent) than for low-motivation problems (overrun = 28 percent), $t(30) = 2.27$, $p < .05$. Thus, there does seem to be a motivational component to subjects' tendency to overestimate what they can accomplish in a given period of time.

As discussed above, plan overrun reflects an underestimation of the times required to perform individual planned actions. In the errand-planning task, there are two categories of planned actions: errands and travel. For high-motivation problems, subjects underestimated required errand times by a mean of 6.27 minutes, or 30.5 percent. For low-

motivation problems, they underestimated errand times by 4.25 minutes, or 16.6 percent. This difference was significant, $t(30) = 3.56$, $p < .001$.

The results were somewhat different for travel time. On the average, subjects actually overestimated required travel times. However, the pattern of results was the same. Subjects overestimated required travel times by 16.9 percent for low-motivation problems but by only 6.5 percent for high-motivation problems. This difference was significant, $t(30) = 3.31$, $p < .01$. Thus, although subjects overestimated required travel times in general, they generated lower estimates for the high-motivation problems than for the low-motivation problems.

Although the group data seem to indicate opposite errors in subjects' estimates of errand time and travel time, individual subject "profiles" show that this was not a reliable result. For each subject, we computed the mean error in errand and travel time estimates across the four problems. This provided us with a measure of subjects' general tendencies to overestimate or underestimate each time requirement. We then tabulated the number of subjects who overestimated both time requirements, neither, or one of the two. These data appear in the following matrix:

Errand Times

Travel Times	Underestimate	Overestimate
Underestimate	9	2
Overestimate	14	6

About half the subjects (fifteen) produced consistent errors on errand and travel estimates, while the other half (sixteen) produced opposite errors. These data do not differ from the chance expectation, $X^2 = .516$.

Nonetheless, subjects obviously showed a stronger tendency to underestimate errand times than to underestimate travel times. Subjects probably used somewhat different procedures for estimating the two kinds of required times. For errand times, subjects had to retrieve world knowledge, whereas they could compute travel times using the information provided in the problem statement and some simple arithmetic. Apparently, the former procedure produced unrealistic time estimates, while the latter produced more conservative estimates. It is interesting that the motivational factor investigated in this experiment influenced both estimation procedures.

To summarize, these results show that subjects' motivation to accomplish the errands in a problem influenced their estimates of both errand and travel times. Increased motivation led subjects to generate lower estimates of required times. Unrealistic errand estimates were the main determinants of plan overrun. At both high and low motivation levels, subjects underestimated the time required to accomplish individual errands and, as a consequence, included too many errands in their plans. By contrast, they tended to overestimate the time required to traverse planned routes. This overestimation of travel times improved the virtual realism of subjects' plans.

V. CONCLUSIONS

People tend to plan more than they can accomplish in the available time. The vast majority of subjects we tested exhibited this tendency for a variety of specific problems within an errand-planning paradigm. Subjects' plans actually "fit" in the available execution time only for problems that provided more than enough time to accomplish all of the tasks under consideration. We observed these effects when evaluating subjects' plans against normative estimates of the time requirements of component tasks and when evaluating them against individual subjects' own prior estimates of time requirements. Thus, the planning process seems to bias subjects to generate lower time estimates than they might in other contexts.

Although planning has typically been viewed as an essentially cognitive process (Byrne, 1977; Hayes-Roth & Hayes-Roth, 1979; Miller, Galanter, & Pribram, 1960; Newell & Simon, 1972; Sacerdoti, 1975), our results suggest that unrealistic planning behavior may reflect both cognitive and motivational factors. Experiment 2 showed that people generate lower time estimates when they operate at a high level of abstraction than when they operate at a low level of abstraction. Because people do not usually decompose tentative plans into their lowest-level constituents, this cognitive factor leads them to systematically underestimate the actual time requirements of the actions they plan. Experiment 3 showed that people generate lower time estimates when they are highly motivated to accomplish the tasks under consideration than when they are less motivated. Because planning explicitly focuses on

the establishment and achievement of goals, this motivational factor also contributes to the general tendency to underestimate the actual time requirements of planned actions.

Experiment 1 confirmed the earlier observation that people's tendency to overestimate what they can accomplish increases with time stress. The more difficult it is to accomplish all of the tasks under consideration in the available time, the greater the proportion by which the planned activity exceeds the available time. The cognitive and motivational factors discussed above may interact to produce this effect. The set of tasks under consideration effectively determines the planner's motivation level. As the number of tasks increases with respect to the time available, the planner's motivation increases and there is a tendency to generate lower time estimates. However, working at a low level of abstraction may limit the planner's tendency to underestimate required times. The actions under consideration at this level are more concrete, and the planner may have less uncertainty about true time requirements. For example, the planner may know more about the true time required to pay a cashier than about the time required to buy a shirt. Thus, motivational factors may have a greater impact when the planner works at a high level of abstraction than when the planner works at a low level of abstraction.

Although we have examined only a narrow range of time estimation tasks, the need to estimate resource requirements is quite general and fundamental to all planning problems. For the more general class of errand-planning problems, planners might also estimate energy and financial requirements. For other types of planning problems, planners might

estimate requirements for space, fuel, personnel, etc. Estimation of requirements for these other types of resources might also reflect the influence of cognitive and motivational factors such as those discussed above.

THE ATTRIBUTION PROBLEM

People's apparent inclination to underestimate required resources raises another question: Why don't people learn from experience? Certainly people have had many opportunities to estimate how long it will take to perform errands such as those used in the present experiments, and they have received feedback regarding the accuracy of those estimates. Similarly, in most other task domains, people have many opportunities to estimate resource requirements and to receive feedback regarding those estimates. Why do people not acquire a consistent set of realistic estimates?

We suspect that people's failure to learn from experience may be due, in part, to an attribution problem. In order to learn from experience, the planner must be able to identify valid contingencies between his or her planning behaviors and the outcomes of plan execution. This process may be impeded by the inherent complexity of the problem or by limitations on human judgment.

Planning problems are particularly complex. In the errand-planning task, for example, the finished plan represents the combined contributions of many planning subprocesses, such as estimating errand time requirements, estimating route time requirements, selecting errands for inclusion in the plan, sequencing errands, designing efficient routes,

and anticipating potentially interfering events. Plan execution does not provide feedback on the quality of each of these subprocesses, but only on the outcomes of the plan as a whole--what errands are accomplished, what resources are consumed, and perhaps a few details, such as the errands at which the planner arrived late. This feedback is made more ambiguous by the possibility that situational factors, such as the occurrence of unanticipated low-probability events, also contribute to plan outcomes. Thus, the feedback planners receive from plan execution is not diagnostic; it does not permit reliable attribution of plan outcomes to appropriate antecedent planning behaviors.

Certain biases in human judgment may interact with the complexities of attribution. Several studies have shown that people tend to attribute success at a task to internal factors such as their own ability or effort, but they tend to attribute failure to external factors such as bad luck or task difficulty (Arkin, Gleason, & Johnston, 1976; Snyder, Stephen, & Rosenfield, 1976; Wortman, Costanzo, & Witt, 1976). In the present context, this could lead planners to attribute positive plan outcomes to their planning skills and to attribute negative plan outcomes to situational factors.

CORRECTION OF BIASES IN RESOURCE ESTIMATION

Because resource estimates have a substantial impact on the efficacy of a final plan, the correction of errors or biases is an important area for future research. Based on the present findings, we can suggest two methods for consideration. First, we might be able to identify an "optimal" level of abstraction for planning in particular problem

domains and to induce planners to operate at that level. The optimal level should minimize the planner's attention to extraneous detail, while ensuring attention to those details that influence planning subprocesses, such as resource estimation. Experiment 2 demonstrated the feasibility of this approach, and similar "decomposition" techniques have been investigated in decision-analysis domains (Armstrong, Dennis-ton, & Gordon, 1975; Leal & Pearl, 1977; Merkhofer, Korsan, Miller, & Robinson, 1977). Second, we might be able to regiment planners' resource estimation activities to protect them against motivational factors. For example, we might elicit a planner's estimates in a neutral context and then provide them as inputs during the planning process.

Of course, neither of these methods guarantees realistic resource estimates. For example, such techniques may reduce planners' underestimation errors without eliminating them. In addition, situational factors can influence the accuracy of resource estimates. For example, unanticipated events during plan execution can usurp resources from planned activities. These may include events that the planner has overlooked and also low-probability events that the planner could not reasonably be expected to anticipate. What these methods can do is improve the reliability of individual planners' time estimates and protect them from the effects of incidental cognitive and motivational factors of which the planner is unaware.

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